Experimental study of the elementary excitations in a Bloch wall

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The spectrum for low-amplitude oscillations of a monopolar domain wall in yttrium garnet ferrite wafers is studied. Resonances caused by the domain-wall flexural standing waves in the sample is detected. The dispersion law for these waves is determined for the first time.

The existence of domain walls in a ferromagnet leads to a marked change in the magnon spectrum, which is characteristic for a uniformly magnetized crystal. As the theoretical studies have shown,[1–3] the domain walls not only scatter bulk spin waves but also cause the appearance of new branches in the spectrum of magnetic excitations in the parts of the domains adjacent to the domain walls and directly in the domain walls. Some excitations manifest themselves, in particular, as flexural oscillations of the domain walls and affect their translational velocity.

At the same time, the spectrum of such excitations of domain walls has not been studied experimentally. Only the nonuniform oscillations of the domain walls, which are caused by the Bloch lines[4] or the nonuniform distribution of the internal magnetic field in the garnet film, have so far been studied.[5] In the present letter we report the results of the first experimental study of the spectrum of elementary excitations of a 180° monopolar domain wall in yttrium garnet ferrite single crystals.

The domain walls studied are separated by domains with magnetization vectors **M**, which lie in the (112) plane of the wafer. To eliminate the effects associated with the collective behavior of domain walls,[5] each wafer is cut in the shape of a rectangular prism stretched out considerably along the $[11\bar{1}]$ axis, so that it contains a single 180° domain wall directed parallel to $(\bar{1}10)$. The monopolar state of domain walls is achieved through a simultaneous imposition on the crystal of a sinusoidal magnetic field (H_x is directed parallel to the magnetization of the domains) and a static magnetic field (H_z is directed normal to the wafer plane).[6] The displacement of domain walls is detected (by using a photomultiplier and a selective microvoltmeter) from the change in the intensity of a linearly polarized light transmitted through a region of the crystal which contains a part of the domain wall (approximately half its width, as shown in the inset in Fig. 1) and a part of the neighboring domain.[6]

Figure 1 shows the amplitude of the magneto-optical signal (y_0) versus the frequency (ν) of the external magnetic field H_x which displaces the domain wall a distance much shorter than its width. We see that this curve is a set of resonance peaks, whose amplitudes decrease monotonically as the frequency is increased. The plot of the resonant frequency (ν_n) of the peak versus its number (n) is, as can be seen in Fig. 2, virtually linear, and the peak half-width ($\Delta\nu_n$), measured at the 0.7

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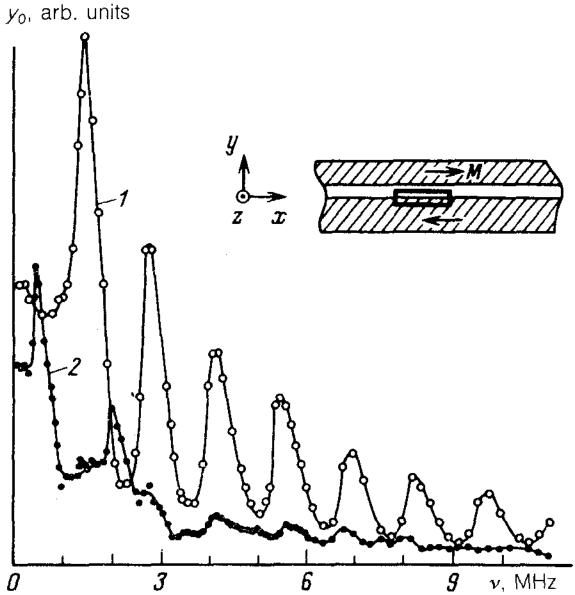

FIG. 1. Frequency dependences of the amplitude of the magneto-optic signal on the domain wall which executes forced oscillations in an external sinusoidal magnetic field of amplitude $H_x^0 = 18.6$ mOe. 1—Monopolar domain wall, $H_2 = 22.6$ Oe; 2—domain wall with Bloch lines, $H_z = 0$. Inset—schematic representation of the sample and of its part where photometric measurements are carried out.

level of its height, changes as n increases from ~ 0.4 to ~ 0.5 MHz. The characteristics of the curves $y_0(\nu)$ do not depend on the change in the position of the region of photometric measurements along the domain wall or on the sample length. After the wafer is thinned down, however, the slope of the $\nu_n(n)$ curve increases (Fig. 3).

The amplitudes of the resonant peaks decrease sharply when the domain wall is broken up into subdomains. On curve 2 in Fig. 1, which is measured when the domain wall contains Bloch lines, we see virtually no regular oscillations of the vibration amplitude of the domain wall but we do see a new peak (near 0.5 MHz), which is

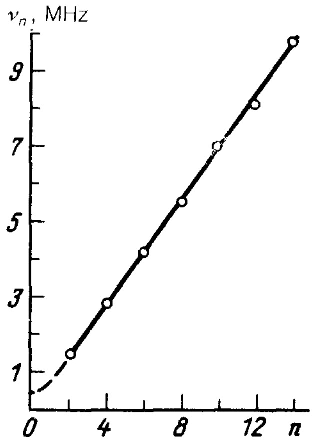

FIG. 2. The resonant frequency of the peak (ν_n) versus the peak number (n), plotted from curve 1 in Fig. 1.

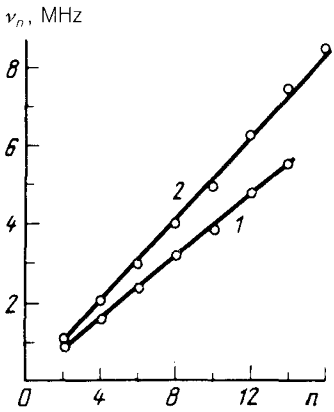

FIG. 3. The influence of the thickness of the sample on the ν_n-versus-n curve. $H_x^0 = 18.6$ mOe, $H_z = 22.6$ Oe. 1—$d = 35\ \mu$m; 2—$d = 20\ \mu$m.

caused by the oscillation of the Bloch lines at the natural frequency.[6] Finally, it is important to note that the $y_0(\nu)$ curve for a monopolar domain wall does not change when the sample is placed in a viscous medium (glycerin) or when its edges are cemented.

The experimental data presented here justify the assertion that they reflect the resonant excitation of the standing flexural waves of a monopolar domain wall in the bulk of the wafer. Taking into account the particular features of the structure of the surface regions of a moving domain wall and the fact that it is not pinned at the surface of the crystal, we can assume that only even modes ($n = 2, 4, ...$) are excited in a uniform field H_x.[5] Since the frequency of the left-most peak on the $y_0(\nu)$ curve increases in the same way as that of the other peaks when the wafer is thinned down (see Fig. 3), we assume that it is also caused by the flexural oscillations of the domain wall ($n = 2$). The resonance of the translational motion of the domain wall as a whole (i.e., for $n = 0$), on the other hand, does not occur for some reason which causes the relaxational decrease of the initial part of the $y_0(\nu)$ curve.

The dispersion law for the flexural waves of the domain wall, shown in Fig. 2, can be explained qualitatively on the basis of the analysis of the Slonczewski linearized equations.[7] Such an analysis, in which the geometry of our experiment is taken into account and which is based on an approximation of a strongly anisotropic magnetic material, leads to an expression for the resonant frequencies of the flexural oscillations of the domain wall:

$$\omega_n = (\Omega^2 + s^2 k_n^2 - \omega_\alpha^2/2)^{1/2} , \qquad (1)$$

where $n = 0, 2, 4, ..., k_n = \pi n/d$; d is the wafer thickness; $\Omega^2 = (\kappa/m)(1 \pm H_z/8M)$ for $H_z \lessgtr -8M$; κ is a coefficient characterizing the elastic force which returns the domain wall to the original position as a result of its displacement, $m = (2\pi\gamma^2\Delta_0)^{-1}$, $\Delta_0 = (A/K)^{1/2}$; A and K are the exchange and anisotropy constants, respectively; $\omega_\alpha = 4\pi M\gamma\alpha(1 \pm H_z/8M \pm h)$, $h = \kappa\Delta_0/8\pi M^2$, α is the dissipation parameter in the Landau-Lifshitz-Hilbert equation; and $s^2 = 8\pi A\gamma^2(1 \pm H_z/8M \pm h)$ for $(H_z/$

$8M+h) \lessgtr -1$. The dependence of Ω, ω_α, and s on the field H_z was confirmed qualitatively in our experiment. The dashed part of the curve in Fig. 2 was constructed on the basis of this expression and on the basis of the experimental data for $\omega_\alpha = 2\pi\Delta\nu_2$ and $\nu_n(n)$.

We wish to emphasize that the minimum value of the parameter α found from the width of the first resonance peak $[\alpha = \Delta\nu_2/2\gamma M = (0.8 \pm 0.1)\times 10^{-4}]$ is in good agreement with the value calculated from the data on the measurement of the ferromagnetic resonance line width ($\alpha \simeq 0.7\times 10^{-4}$). However, the energy gap in the spectrum, ~ 0.5 MHz (Fig. 2), does not coincide with the calculated value ($\Omega/2\pi \cong 7$ MHz). In calculating this gap we used the value of κ determined on the basis of the measurement of the $y(H_x)$ curve when the domain wall was moved a distance of $y \gg \Delta_0$. The measured value of the phase velocity of the flexural waves, ~ 40 m/s, is also in disagreement with the calculated value, $s \cong 570$ m/s.

The indicated discrepancies may be attributed to the fact that the structure and the structure-related surface energy of the domain wall in yttrium garnet ferrite differ markedly from those that were used in the calculation based on Eq. (1), which was carried out in the context of the theory[7] for strongly anisotropic magnetic materials. The experimental data presented above show that a theory for slightly anisotropic ferromagnetic materials must be developed.

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